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Postmergence Grass Control in Soybean Using Diclofop-methyl, Difenopenten and Sethoxydim

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POSTEMERGENCE GRASS CONTROL IN SOYBEAN USING DICLOFOP-METHYL, DIFENOPENTEN AND SETHOXYDIM

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DICLOFOP-METHYL, DIFENOPENTEN AND SETHOXYDIM

This thesis is approved as a creditable and independent investigation by the candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Annual grasses and broadleaf weeds reduce soybean [Glycine max (L.) Merr.] yields (19, 22, 24, 29). Preplant and preemergence herbicide applications control these weeds in production systems which utilize the moldboard plow but are less effecitve in conservation tillage systems. Preplant herbicides provide less effective weed control in "reduced tillage" practices because incorporation is not accomplished. Preemergence herbicides are less effective in conservation tillage systems because the heavy crop residue does not allow contact of the chemical with the seed bed. The poor coverage with preemergence herbicides allows many weeds to escape control. Untimely weather conditions (rains, wind, etc.) prevent proper application of preemergence herbicides in both conventional and conservation tillage systems. Therefore, soybean growers are relying on postemergence herbicide applications to control summer annual weeds.

The judicious use of herbicides is an additional factor when considering the use of a postemergence chemical. The use of a postemergence herbicide allows a grower to selectively treat problem areas in his fields. The reduced usage of chemical is not entirely feasible with either preplant or preemergence herbicides. Treatment of entire fields may be necessary as weeds are not visible at the time of application.

Herbicidal efficacy of postemergence herbicides is often influenced by biological, climatological, chemical and mechanical factors. Postemergence herbicide efficacy and crop tolerance can be directly influenced by many factors, such as combining a grass herbicide with a broadleaf herbicide, by the growth stage of the weeds at application, by spray volume at application, by rainfall following postemergence herbicide application and by the presence of perennial weeds.

The objectives of this research were to:

(1) determine if tank-mix combinations of diclofop-methyl ((±)-2[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid), difenopenten (4-[4-[4-(trifluoromethyl)phenoxy]phenoxy] -2-pentenoic) or sethoxydim (2[1-(ethoxyimino)butyl]-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one) each with bentazon [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] are antagonistic for control of either annual grasses or broadleaf weeds and if these combinations are safe when used on soybeans.

(2) evaluate the influence of the growth stage of annual grasses at herbicide application on weed control using diclofop-methyl, difenopenten and sethoxydim.

(3) determine if different water carrier volumes influence the performance of the postemergence herbicides on control of the annual grasses.

(4) determine the rainfast characteristics of the three graminicides when applied to annual grasses.

(5) determine if quackgrass [Agropyron repens (L.) Beauv. # AGRRE] could be effectively controlled using diclofop-methyl, difenopenten or sethoxydim at higher rates than used for annual grass control and if these elevated rates have a phytotoxic effect on soybeans.

LITERATURE REVIEW

An increase in the use of postemergence herbicides in soybean production has been noted in recent years. This interest in postemergence herbicides is largely due to the adoption of minimum and no-till farming practices. Hill suggested that in the decade ahead there will be a considerable increase in conservation farming acreages (14). The use of postemergence herbicides is well suited to the needs of growers who practice minimum or no-till farming practices.

Influence of annual weeds on soybeans.

Crop losses due to early season weed populations in soybeans are of primary concern to growers. Staniforth and Weber established a study to determine the soybean yield losses associated with both annual grasses and broadleaf weeds (29). The study was designed such that weeds were physically removed progressively throughout the growing season. This procedure allowed the determination of the influence of weed pressure on soybean yield. They found that the yield losses were not substantial until the annual grasses were allowed to remain in the crop after the soybeans were in full bloom. In the same study, broadleaf weeds did not substantially reduce yields until weeds were allowed to grow in the crop after the soybean had started to form pods. Knake and Slife conducted a study to determine the influence of a giant foxtail (<u>Setaria faberi</u>

Herrm. # SETFA) population on soybeans (19). They concluded that as the giant foxtail population increased the soybean yields decreased. Further, they suggested that as the giant foxtail population increased the crop height decreased. These observations were in agreement with the results of Staniforth and Weber. Weber and Staniforth (33) established a four year trial to determine the influence of moisture on soybeans when infested with yellow foxtail (Setaria lutescens (Weigel) F. T. Hubb. # SETLU). They reported that the greatest soybean yield reduction due to the yellow foxtail occurred when there was adequate moisture throughout the entire season. Later, Staniforth (30) established a study to determine the competitive effects of yellow foxtail on soybeans under different moisture conditions. He found that soybean yield reduction due to the yellow foxtail was most severe under conditions of moisture stress starting at first pod and continuing until maturity of the soybeans. This conclusion contradicted the earlier work with Weber. It is not uncommon in South Dakota to have adequate early season moisture, followed by late season moisture stress.

Influence of adjuvants on graminicides.

The use of spray adjuvants has been regarded as a method of increasing the level of weed control with a postemergence herbicide. Hartzler and Foy (9) established a study to determine if various adjuvants with sethoxydim could enhance weed control. They reported that an adjuvant was helpful in increasing the weed control, but that no particular adjuvant was superior to any other. Further, they indicated that with any of the adjuvants sethoxydim provided excellent crop safety to the soybeans.

Interaction of grass and broadleaf herbicide combinations.

Many soybean fields have a mixed weed population of both annual grasses and broadleaves. This fact requires that attention be directed to providing a herbicide application that could control both types of weeds. The herbicides under consideration are regarded as primarily annual grass control chemicals. To achieve a broad spectrum of control would then require a tank-mix combination of a grass herbicide and a broadleaf herbicide. Unfortunately, antagonism affecting weed control performance has been observed with many combinations. Qureshi and Born (25) established a study to determine the possible interaction of diclofop-methyl with MCPA [(4-chloro-2-methylphenoxy)acetic acid]. They observed that an antagonistic effect could occur, reducing the effectiveness of the diclofop-methyl in controlling wild oats (Avena fatua L. # AVEFA). This conclusion was in agreement with a wild oat study by Todd and Strobbe (31). Later, a study was undertaken by Wax, Stevens and Zajicek (32) using diclofop-methyl and sethoxydim in combination with bentazon. They reported that the diclofop-methyl with bentazon combination reduced the efficacy of control of the giant foxtail. It was reported that no antagonism existed for the sethoxydim with bentazon combination. Nalewaja et al. (23) established a trial to compare diclofop-methyl, difenopenten and sethoxydim each with and without bentazon. They observed that antagonism existed with the combinations of bentazon with diclofop-methyl, difenopenten and sethoxydim, which reduced the control of yellow foxtail. Campbell and Penner (4) established a study to determine the compatibility of diclofop-methyl and sethoxydim with bentazon. They determined that the combination of diclofop-methyl with bentazon had an antagonistic effect on the grass control, but that the combination of sethoxydim with bentazon had no antagonism. A study of the compatibility of sethoxydim with bentazon was done by Hartzler and Foy (10). They concluded that the combination of sethoxydim with bentazon did reduce the control of large crabgrass (Digitaria sanquinalis (L.) Scop. # DIGSA). They further indicated that a sequential application of the two compounds did not cause antagonism. In two studies established by Harvey and Jansen (11, 12), the writers compared sethoxydim to sethoxydim with bentazon for annual grass and broadleaf weed control. They found that the combination treatment had little effect on the control of common lambsquarters (Chenopodium album L. # CHEAL), redroot pigweed (Amaranthus retroflexus L. # AMARE), or velvetleaf (Abutilon theophrasti Medic # ABUTH). They did find a slight reduction in the control of giant foxtail with the combination treatment. Overall, the results of the studies were inconclusive as to whether or not antagonism did occur with the compounds under study.

Influence of weed stage of growth on graminicides.

The application window of postemergence herbicides is a factor affecting their acceptance and use by soybean growers. Schreiber et al. (26) established a study to determine if the application of diclofop-methyl was influenced by the stage of growth of large crabgrass, barnyardgrass (Echinochloa crus-galli (L.) Beauv. # ECHCG), and giant foxtail. Applications were only one week apart, but the growth stages of the annual grasses were substantially different. The authors reported that the herbicide was less effective when applied to larger grasses. Gealy and Slife (8) investigated the influence of difenopenten applications at various growth stages of giant foxtail. They found that difenopenten provided excellent control when applied to giant foxtail any size from 5 cm to 40 cm tall. They observed that at the later application timings the difenopenten developed weed toxicity slower. Kapusta and Gentsch (16) undertook a study to determine the influence of sethoxydim when applied at various times to giant foxtail. They found that poorer giant foxtail control could be expected when the application was delayed until the six- to eight-leaf stage. In a similar study conducted by Harvey and Jansen (13), the authors discovered that the application timing was not important when the giant foxtail was evaluated late in the season. This conclusion contradicts the previous study regarding the same annual grass.

Effect of water volume on graminicides.

The amount of water carrier can considerably influence the performance of postemergence herbicides. Growers are interested in reducing the water volume to make their sprayers more efficient. To be most effective, many postemergence herbicides need a sufficient water volume to provide adequate weed coverage. Martin and Regimbal (21) conducted a study to determine the influence of a conventional sprayer (set at 20 gpa) versus a controlled droplet sprayer (set at 1.5 and 4.5 gpa) for control of shattercane (Sorghum vulgare Pers. # SORVU) with sethoxydim. Forage sorghum (Sorghum bicolor (L.)Moench.) was used to stimulate the shattercane. They reported that there was little performance difference between the two types of sprayers. Inman and Kapusta (15) investiaged the use of controlled droplet sprayers set at various water volumes in comparison to the conventional sprayer set at 20 gpa for control of giant foxtail with sethoxydim. The authors found that sethoxydim when applied with the conventional sprayer provided better giant foxtail control than when applied with the controlled droplet sprayer at any volume.

Influence of rainfall following graminicide application.

Rainfall occurring shortly after a postemergence herbicide application has been known to reduce the weed control efficacy (3,7). This is a factor which may influence the usage of a herbicide in an area where unexpected storms may occur. Coultas and Harvey (5) conducted a study using a rainfall simulator to determine the effects of moisture soon after herbicide application. They concluded that the use of a rainfall simulator could be effective in determining performance of herbicides in field-like conditions. Behrens and Elakkad (1) established a study using a rainfall simulator to determine the effect of rainfall shortly after the application of 2,4-D [(2,4-dichlorophenoxy)acetic adic]. They indicated that rainfall soon after the herbicide application reduced the weed control. West et al (34) established a trial to determine the effect of diclofop-methyl for the control of barnyardgrass when followed by an overhead irrigation. They concluded that irrigation after application enhanced control of barnyardgrass. This is an area of research which could be quite helpful to growers who anticipate using postemergence herbicides.

Effect of graminicide applications on quackgrass.

Quackgrass is a difficult-to-control perennial grass. Control is particularly difficult in row crops, where crop injury is a primary concern. Westra and Wyse (35) established a study to determine the effects of difenopenten and sethoxydim for control of quackgrass. They found that sethoxydim was effective at rates of 1.68 kg/ha with either one or two applications. Kells and Meggitt (18) conducted a similar study on quackgrass. They concluded that difenopenten and sethoxydim provided control when applied to 18 to 22 cm quakcgrass. Bhowmik and Doll (2) conducted a study to determine if sequential applications or cultivation could increase the control of quackgrass with difenopenten and sethoxydim. The authors reported that cultivation after a postemergence application of sethoxydim at 0.5 and 0.75 kg/ha did increase the soybean yields. They did not report either the time interval between application and cultivation or the response of the quackgrass to this split treatment. In a study conducted by Simkins and Doll (27), diclofop-methyl and sethoxydim were applied at various rates for quackgrass control. The authors found that difenopenten at 2.0 kg ai/ha was the most effective of the two compounds for control of quackgrass. The result of the studies were inconclusive, except that cultivation seemed to enhance control.

MATERIALS AND METHODS

Effect of bentazon tank-mixes on herbicide performance

'Corsoy' soybeans were planted in 15 cm rows on June 4, 1980, near Aurora, South Dakota, under a center-pivot irrigation system. The soil texture was a silt loam with an organic matter content of 3.6% and a soil pH of 6.7.

The herbicide treatments were composed of diclofop-methyl at 0.0, 0.56, 1.12 and 2.24 kg/ha, difenopenten at 0.0, 0.21, 0.43 and 0.84 kg/ha, and sethoxydim at 0.0, 0.12, 0.28 and 0.56 kg/ha, each with bentazon at 1/12 kg/ha. Difenopenten treatments had crop oil added at 0.5% (v/v). Sethoxydim treatments had AtPlus 411-F oil added at 1.0% (v/v). The following herbicides and rates were considered to have equivalent annual grass control activity: diclofop-methyl at 1.12 kg/ha, difenopenten at 0.43 kg/ha and sethoxydim at 0.28 kg/ha. All chemicals were applied on July 1, when the soybeans were in the three- to four-trifoliate stage of growth. These applications were made using a one-wheel, bicycle-type sprayer. The sprayer was calibrated to deliver 187 L/ha spray volume. The sprayer was operated at 4 kph with a boom pressure of 2.25 kg/cm². The 2 m spray boom had six Tee-Jet 8002 flat fan nozzles, set at 51 cm intervals. The boom was adjusted to spray 46 cm above the soybean canopy. Plot size was 3 by 12.2 m.

The experiment site, at Aurora, had a natural population of weeds, which principally included green foxtail [*Setaria viridis*

(L.) Beauv. # SETVI], common lambsquarters (Chenopodium album L. # CHEAL) and volunteer corn (Zea mays L. # ZEAMX). At the time of herbicide application, the green foxtail had 4 to 5 leaves; the common lambsquarters was 10 to 15-cm tall; and the volunteer corn was 25-cm tall. The weed densities at application were 90, 9 and 1 plants/m², respectively. Dew was present on the plant leaves during the herbicide applications. Air temperature was 23.3°C with no wind. The soil profile had adequate moisture due to recent irrigation.

This experiment was established as a split-plot design replicated four times. Main plots were the grass herbicides and subplots were the four rates of the grass herbicides. Visual weed control evaluations were recorded July 6, July 16 and July 31. Visual weed control evaluations were based on percent control. Crop height measurements were taken July 19. Green foxtail and common lambsquarters plant dry weights were harvested July 29. Two subsamples from a 0.25 m² area were taken from each plot. After clipping, the plant samples were separated by species. Plant samples were dried at 40°C and dry weights recorded. The soybeans were harvested for grain yields with a small plot combine. The grain samples were cleaned and yields recorded.

Analysis of variance was done using the PROC ANOVA procedures from SAS (Statistical Analysis System). The Bayes Least Significant Difference (K ratio = 100) was used to establish significance between individual treatment means (28).

In 1981, 'Hodgson 78' soybeans were planted in 91 cm rows, on May 29, near Beresford, South Dakota. The soil texture was a silty clay loam with an organic matter of 3.8% and a soil pH of 7.2.

The herbicide treatments were diclofop-methyl at 0.56, 1.12 and 2.24 kg/ha, difenopenten at 0.21, 0.43 and 0.84 kg/ha, and sethoxydim at 0.12, 0.28 and 0.56 kg/ha. The grass herbicides were applied alone and in combination with bentazon at 1.12 kg/ha. A bentazon treatment at 1.12 kg/ha and an untreated check were included for comparison. Herbicide application was made July 17, when the soybeans were in the flowering growth stage. The one-wheel, bicycle-type sprayer was used for the herbicide application, as described for the 1980 trial.

The weeds were exceptionally large at the time of chemical application since early season rains had delayed application. The green foxtail present at application was 36 to 51 cm high. The smooth pigweed (<u>Amaranthus hybridus</u> L. # AMACH) was 20 to 25 cm tall at the time of herbicide application. The air temperature was 22.2°C, with a southeastern wind at 3.2 to 8.0 k/h. The moisture level in the soil profile was close to field capacity.

The trial was a randomized complete block design with four replications. Plot size was 3 by 12.2 m. Visual weed control observations were recorded on July 22, August 17 and September 30.

Visual weed control evaluations were based on percent control relative to the untreated check (untreated check = 0% control, complete control = 100% control). Weed samples were harvested August 17 and September 30. Soybean plant heights were measured August 17. Soybeas were harvested with a plot combine on October 7. The weed samples and soybean grain harvest samples were handled as previously described. Analysis was done as previously described for the 1980 experiment.

Effect of time of herbicide application on performance

At the Southeast South Dakota Research and Demonstrattion Center, near Beresford, South Dakota, 'Evans' soybeans were planted on June 10, 1980. A four-row planter, set on 76 cm spacings, was used to seed the soybeans 3.8cm deep. The soil texture was a silty clay loam with 3.8% organic matter and soil pH of 7.2. Metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one] was applied at 0.43 kg/ha and incorporated with a tandem disc prior to planting.

At each of the three herbicide application times, treatments were established consisting of an untreated check, diclofop-methyl at 1.12 kg/ha, difenopenten at 0.43 kg/ha and sethoxydim at 0.28 kg/ha. Difenopenten and sethoxydim treatments had crop oil added, as previously described. The first application was July 9, when the soybeans were in the fourth trifoliate and the green foxtail was 50 to 8-cm tall. The second application was made July 17, when soybeans were 31 cm tall and the green foxtail was in the eight-leaf to heading stage. The third application was August 5, when the soybeans were 51-cm tall and the green foxtail was 41 to 51 cm tall.

In 1981, the variety 'Hodgson 78' soybeans were planted in rows 91 cm apart on May 29, at the Southeast South Dakota Research and Demonstration Center. The treatments as previously described were applied at four different times, Table 1. The first application was made June 23, when soybeans were in the one-to three-trifoliate stage of growth and the green foxtail was in the one- to three-trifoliate stage of growth and the green foxtail was in the one- to three-leaf stage of growth. The second application was July 1, when soybeans were in the third-trifoliate stage of growth and the green foxtail was in the three- to four-leaf stage of growth. The third application was July 16, when the soybeans were in the flowering stage of growth and the green foxtail was in the eight-leaf to heading stage of growth. The fourth application was July 21, when the soybeans were 51 to 76-cm tall and the green foxtail was 30 to 61-cm tall and heading.

All treatments were applied with a one-wheel, bicycle-type sprayer, as previously described. Climatic conditions, at various application times for both years, are described in Table 1.

In 1980, visual weed evaluations were made August 5 and September 18. In 1981, green foxtail visual weed control evaluations were recorded July 30, August 17 and September 17. Weed samples were harvested on the same dates. The weed samples were dried and weighed, as previously described. A crop height measurement was

Table 1. Climatic factors for the various time of application studies, 1980 and 1981.

	1980			1981			
Application Date	7/9	7/17	8/5	6/23	7/1	7/16	7/21
Cloud Cover	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Rel. Humidity, %	40	40	30	65	60	75	52
Air Temp., °C	23	22	24	15	22	21	27
Wind Speed, k/h	0	5-8	0-3	0-3	6-11	0	0
Wind Direction	-	SE	W	SE	SSE	-	-
Soil Moisture, at 5 cm	Dry	Dry	Dry	Moist	Moist	Moist	Moist
Soil Temperature, at 5 cm, °C	21	24	27	17	21	22	26

recorded August 17. The soybeans were harvested with a plot combine on September 29.

In both years, the treatments were arranged in a randomized complete block design with four replications. Plot size was 3 by 12.2-m long. Analysis for both years was performed as described previously.

Effect of spray volume on herbicide performance

Field studies were established near Brookings and Beresford, South Dakota, in 1980 and 1981, respectively. The studies included diclofop-methyl at 1.12 kg/ha, difenopenten at 0.43 kg/ha, sethoxydim at 0.28 kg/ha, and a control. Difenopenten and sethoxydim had crop oils added, as previously described. All treatments were applied at three spray volumes, 66, 140 and 299 l/ha. Water, as the herbicide carrier, was used in all applications. Only water was applied to the controls. In both years, the treatments were arranged in a split-plot design. The main plots were the chemicals and the control, with the subplots as the spray volumes. The trials had four replications; plot size measured 3 by 12.2 m. Each plot consisted of three rows 76 cm apart. 'Evans' soybeans were planted in 1980 and 'Hodgson 78' were planted in 1981.

In 1980, treatment application was June 30, when the soybeans were in the third-trifoliate stage and the yellow foxtail was 5 to 10 cm-tall. The soil texture was a silty clay loam with 3.2% organic matter and a soil pH of 6.5. In 1981, treatment application was

July 21, when the soybeans were flowering and were 91-cm tall. The green foxtail was 61 to 91-cm tall. The soil texture was a silty clay loam with an organic matter content of 3.8% and a soil pH of 7.2. Bentazon at 1.12 kg/ha was applied postemergence on July 29 to control annual broadleaves.

A tractor-mounted sprayer was used to make the herbicide applications at the Brookings location. At the Beresford location, a bicycle-type sprayer was used for the treatment applications. Both years the calibration for spray volume was modified by changing the spray nozzle size. Six, Tee-Jet 73077 flat fan nozzles were used to apply the 66 l/ha spray volume, Tee-Jet 8002 nozzles for the 140 l/ha volume and Tee-Jet 8006 nozzles for the 299 l/ha spray volume. Sprayer speed was maintained at 4 khp, with the boom pressure at 2.25 kg/cm². The spray boom was set 46 cm above the crop canopy.

At the Brookings trial, visual weed control evaluations of yellow foxtail were made July 30 and August 26, 1980. Two subsamples of the yellow foxtail present in 0.25 m² were taken from each plot on July 30. Plant samples were dried at 40°C and dry weights recorded. Soybeans were harvested with a small plot combine. Harvest samples were handled as previously described. In 1981, visual weed control evaluations of green foxtail were taken August 17 and September 17. Weed subsamples were collected on the same days. The samples were collected and processed as described above. Crop height recordings were taken August 17. The soybeans were harvested and cleaned as described before. Analysis was done as previously described.

Effect of simulated rainfall on herbicide performance

'Hodgson 78' soybeans were planted June 5, 1981 at the James Valley Agricultural Research and Demonstration Center, near Redfield, South Dakota. Metribuzin was applied at 0.42 kg/ha as a preemergence application on June 5 to control broadleaf weeds. The soil texture was a silt loam with an organic matter of 2.8% and a soil pH of 7.4.

Diclofop-methyl was applied at 1.12 kg/ha, difenopenten at 0.43 kg/ha and sethoxydim at 0.28 kg/ha. Two control treatments were included, one with and one without rainfall simulation. Herbicide applications and the rainfall simulations were made the night of July 6 through July 9. One replication was sprayed and watered on each night. Applications were made at night to minimize the influence of temperature variation and wind. Herbicide applications were made at predetermined intervals. The rainfall simulations were scheduled at the following times: immediately, 0.5, 1, 2, 4, and 8 hours after herbicide application. The rainfall simulator applied 0.62 cm of water in 15 minutes, to simulate a typical thundershower. The rainfall simulation was achieved by having an oscillating 80° flat fan nozzle deliver the water. A metal framework suspended the nozzle and oscillation mechanism 2.7 m above ground level. A pump was regulated to allow 7.1 l/min of water to be delivered to the nozzle at 0.7 kg/cm². A tarp was suspended from the metal framework to prevent wind effects on the rainfall pattern during application. The rainfall simulator applied the water uniformly over a 2.4 by 3-m area.

Table 2 summarizes the climatic conditions at each application. The soybeans were in the one- to three-trifoliate growth stage. The yellow foxtail was 7 to 10-cm tall at treatment application. Application was made using a bicycle-type sprayer, as described before.

This trial was established as a randomized complete block design with four replications. Visual weed Control evaluations were made July 28, August 15 and September 15. Yellow foxtail plant samples were harvested August 15 and September 15. The plant samples were collected, dried and weighed, as previously described. The soybeans were harvested using a small plot combine. Analysis was done as described previously.

Effect of graminidies for quackgrass control

'Corsoy' soybeans were planted near Colton, South Dakota, on May 1, 1981. The soil texture was a silty clay loam with an organic matter of 3.2% and a soil pH of 6.0. Near Brookings, South Dakota, a field of quackgrass was plowed and disked in early June of 1981. The soil texture was a silty clay loam with an organic matter of 3.4% and pH was 6.5. This field was under a center-pivot irrigation system. 'Hodgson 78' soybeans were planted using a conventional planter on June 18. The row spacing was 91 cm, with the soybeans

Table 2. Climatic factors for the various times of application of the rainfall simulation study, Redfield, South Dakota, 1981.

	Climatic Conditions			
Application Date	7/6	7/7	7/8	7/9
Cloud Cover	Clear	Clear	Clear	Clear
Rel. Humidity %	30	30	60	85
Air Temp., °C	31	33	12	11
Wind Speed, k/h	0-3.2	0-3.2	0-3.2	3.2-8.0
Wind Direction	S	S	NW	NW
Soil Moisture, at 5 cm	Dry	Dry	Dry	Dry

planted 5-cm deep. Metribuzin was applied at 0.56 kg/ha, as a preemergence broadleaf control herbicide. The entire trial area received the metribuzin application the same day as the soybean planting.

The herbicides tested at both sites were diclofop-methyl at 1.68, 3.36 and 6.72 kg/ha, difenopenten at 0.64, 1.28 and 2.55 kg/ha and sethoxydim at 0.43, 0.84 and 1.68 kg/ha. Difenopenten treatements had 0.5% (v/v) crop oil added, and sethoxydim had 1.0% (v/v) of AtPlus 411-F oil added. An untreated check was included for comparison. The following herbicides and rates were considered to have equivalent perennial grass control: diclofop-methyl at 3.36 kg/ha, difenopenten at 1.28 kg/ha and sethoxydim at 0.84 kg/ha.

At the Colton location, all treatments were applied June 9, when the soybeans were in the second- to fourth-trifoliate stage of growth. The quackgrass was 15 to 23-cm tall. The air temperature was 29.4°C with a realtive humidity of 45%. Soil temperature was 28.9°C at 5 cm below the soil surface. Winds were from the southeast at 6.4 to 9.6 k/h. The cloud cover was only slight and soil moisture was adequate. At the Brookings location, all treatments were applied on July 6. The soybeans were in the unifoliate- to first-trifoliate stage of growth and the quackgrass was 3 to 8-cm tall. The air temperature was 18.3°C with 85% relative humidity. Dew was present on the surface of the plant leaves. The soil was moist due to a recent irrigation. Individual Canada thistle [Cirsium srvenses

(L.) # CIRAR] plants had glyphosate [N-(phosphonmethyl)glycine] applied September 16. All herbicides were applied with a bicycle-type sprayer, as described previously.

At Colton, visual weed control evaluations were made July 2 and August 4. Evaluations were based on the 0 to 100% scale, relative to the untreated check. At the Brookings location, visual weed control evaluations were made August 4 and August 19. Quackgrass plant samples were harvested July 28 and August 19. The weed samples were collected, dried and weighed as previously described. The soybeans were harvested October 23 and cleaned as previously described.

A randomized complete block design was used for both experiments. Four replications were included for each treatment. Plot size was 3 by 12.2-m long. The analysis was done as previously described.

RESULTS AND DISCUSSION

Effect of bentazon tank-mixes on herbicide performance

Visual weed control of green foxtail at the Aurora site on July 31, 1980 is presented (Table 3). Throughout the following discussion of this experiment, references to the treatments will be by the grass herbicide name and rate only. Understand that all treatments did include bentazon at 1.12 kg/ha. Green foxtail control significantly increased as the rate of the grass herbicide increased. Sethoxydim at the 0.28 and 0.56 kg/ha rates provided significantly better control than did difenopenten at 0.43 kg/ha, which provided significantly better control than did diclofop-methyl at 1.12 kg/ha. Sethoxydim provided greater than 80% control at 0.28 and 0.56 kg/ha. The difenopenten and the diclofop-methyl required 0.84 and 2.24 kg/ha rates, respectively, to achieve at least 80% control. Decreasing green foxtail plant dry weights confirm the control results. Sethoxydim reduced the plant dry weights more than did the difenopenten and the diclofop-methyl. A highly significant negative correlation between visual control and dry weights was observed (R^2 = 0.97). The results of July 6 and July 16 evaluations indicated similar trends, with both the visual control and dry weights.

The results of the volunteer corn visual control evaluation are presented in Table 4. The effectiveness of the grass herbicides tended to increase with each successive rate increase. Greater than

Table 3. Green foxtail visual control (%) as observed on July 31, 1980 and plant dry weights (g) collected on July 29 at Aurora, South Dakota.

Treatment		Green Foxtail	
Herbicide	Rate	Control[a]	Weights[b]
	(kg ai/ha)	(%)	(g)
Diclofop-methyl + Bentazon	0.00 + 1.12	0 E[c]	29.8 DC
Diclofop-methyl + Bentazon	0.56 + 1.12	10 E	26.4 CD
Diclofop-methyl + Bentazon	1.12 + 1.12	35 CD	16.5 BC
Diclofop-methyl + Bentazon	2.24 + 1.12	81 A	7.3 AB
Difenopenten + Bentazon	0.00 + 1.12	0 E	34.6 D
Difenopenten + Bentazon	0.21 + 1.12	20 DE	20.0 B-D
Difenopenten + Bentazon	0.43 + 1.12	60 B	6.3 AB
Difenopenten + Bentazon	0.84 + 1.12	96 A	0.7 A
Sethoxydim + Bentazon	0.00 + 1.12	0 E	23.9 CD
Sethoxydim + Bentazon	0.12 + 1.12	50 BC	9.7 AB
Sethoxydim + Bentazon	0.28 + 1.12	81 A	2.8 A
Sethoxydim + Bentazon	0.56 + 1.12	96 A	1.4 A

[a] 0 to 100% scale, 0% = no control, 100% = total control.

[b] Weights (g) from two subsamples form a 0.25 m^2 area were taken from each plot

[c] Values within a column followed by the same letters are not significantly different using Bayes LSD (K = ratio 100).

[d] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[e] Treatments containing sethoxydim included AtPlus 411-F oil at 1.1% (v/v).

Table 4. Volunteer corn visual control (%) as observed on July 31, 1980 at Aurora, South Dakota.

Treatment		Volunteer Corn
Herbicide	Rate	Control[a]
	(kg ai/ha)	(%)
Diclofop-methyl + Bentazon	0.00 + 1.12	0 E[b]
Diclofop-methyl + Bentazon	0.56 + 1.12	25 D
Diclofop-methyl + Bentazon	1.12 + 1.12	75 BC
Diclofop-methyl + Bentazon	2.24 + 1.12	99 A
Difenopenten[c] + Bentazon	0.00 + 1.12	0 E
Difenopenten + Bentazon	0.21 + 1.12	82 A-C
Difenopenten + Bentazon	0.43 + 1.12	97 A
Difenopenten + Bentazon	0.84 + 1.12	89 AB
Sethoxydim[d] + Bentazon	0.00 + 1.12	0 E
Sethoxydim + Bentazon	0.12 + 1.12	70 C
Sethoxydim + Bentazon	0.28 + 1.12	97 A
Sethoxydim + Bentazon	0.56 + 1.12	99 A

[a] 0 to 100% scale, 0% = no control, 100% = total control.

[b] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[c] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[d] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

Table 5. Common lambsquarters visual control (%) as observed on July 31, 1980 and plant dry weights (g) harvested on July 29 at Aurora, South Dakota.

		Common Lambsquarters	
Herbicide	Rate	Control[a]	Weights[b]
	(kg ai/ha)	(%)	(g)
Diclofop-methyl + Bentazon	0.00 + 1.12	91 A[c]	4.6 AB[c]
Diclofop-methyl + Bentazon	0.56 + 1.12	75 AB	9.2 A-C
Diclofop-methyl + Bentazon	1.12 + 1.12	50 BC	3.9 AB
Diclofop-methyl + Bentazon	2.24 + 1.12	45 BC	2.4 A
Difenopenten + Bentazon	0.00 + 1.12	90 A	2.4 A
Difenopenten + Bentazon	0.21 + 1.12	50 BC	6.3 A-C
Difenopenten + Bentazon	0.43 + 1.12	28 C	7.3 A-C
Difenopenten + Bentazon	0.84 + 1.12	20 C	17.6 C
Sethoxydim + Bentazon	0.00 + 1.12	91 A	1.5 A
Sethoxydim + Bentazon	0.12 + 1.12	40 BC	5.3 AB
Sethoxydim + Bentazon	0.28 + 1.12	78 AB	3.2 A
Sethoxydim + Bentazon	0.56 + 1.12	28 C	16.1 BC

[a] 0 to 100% scale, 0% = no control, 100% = total control.

[b] Values within a column followed by the same letters are not significnatly different using Bayes LSD (K ratio = 100).

[c] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

[d] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[e] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

Table 6. Crop height (cm) measurements recorded July 19, 1980 and soybean yields (kg/ha) harvested at Aurora, South Dakota.

Herbicide	Rate	Soybean Height	Soybean Yield
	(kg ai/ha)	(cm)	(kg/ha)
Diclofop-methyl + Bentazon	0.00 + 1.12	26.1 E[a]	1021 CD[a]
Diclofop-methyl + Bentazon	0.56 + 1.12	24.9 DE	1196 B-D
Diclofop-methyl + Bentazon	1.12 + 1.12	23.5 B-D	1270 A-D
Diclofop-methyl + Bentazon	2.24 + 1.12	21.9 AB	1418 AB
Difenopenten[b] + Bentazon	0.00 + 1.12	27.0 E	756 D
Difenopenten + Bentazon	0.21 + 1.12	24.1 CD	1021 CD
Difenopenten + Bentazon	0.43 + 1.12	20.8 A	1344 A-C
Difenopenten + Bentazon	0.84 + 1.12	22.9 B-D	1378 AB
Sethoxydim[c] + Bentazon	0.00 + 1.12	26.5 E	1041 CD
Sethoxydim + Bentazon	0.12 + 1.12	23.1 B-D	1452 AB
Sethoxydim + Bentazon	0.28 + 1.12	22.3 A-C	1559 A
Sethoxydim + Bentazon	0.56 + 1.12	22.8 A-C	1364 AB

[a] Values within the same column followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[b] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[c] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

80% weed control occurred with difenopenten at all rates, sethoxydim at the 0.28 and 0.56 kg/ha rates and diclofop-methyl at the 2.24 kg/ha rate.

The bentazon alone treatment effectively controlled common lambsquarters when evaluated on July 31 (Table 5). Since the grass herbicides are not perceived to control broadleaves, the common lambsquarters control should be a function of the bentazon entirely, and broadleaf control should not be influenced by the grass herbicides. However, as the rate of the grass herbicide in the tank-mix combination was increased, control of common lambsquarters tended to decrease. The broadleaf plant dry weights increased, but only the highest rates of difenopenten and sethoxydim allowed significantly higher plant dry weights than the bentazon alone. I would infer from the results that the grass herbicides are antagonistic to bentazon; however, there may be other factors to consider.

Crop heights decreased with increasing rates of grass herbicides (Table 6), which may be due to competition between the crop and the weed for sunlight or nutrients. A highly significant negative correlation was observed between visual control evaluations of green foxtail taken on July 31 and crop height ($R^2 = 0.81$).

As evidenced by soybean yield results (Table 6), significantly higher yields occurred with the higher grass herbicide rates. Yields with bentazon alone tended to be lower than when grass herbicides were used in combination with bentazon. A significant negative correlation between crop height measurements and soybean yields was observed (R^2 = 0.80). A significant correlation between green foxtail control and soybean yields was also observed (R^2 = 0.83). The correlation between common lambsquarters visual weed control and crop yield was non-significant (R^2 = 0.31). These correlations indicate that grass pressure, rather than broadleaf control, was the most limiting factor to crop yield.

Table 7 presents the green foxtail visual weed control results and the plant dry weight on September 30, 1981. The visual control evaluations tended to be lower when the grass herbicides were in combination with bentazon, as compared to the same rate of grass herbicide without bentazon. Antagonism may exist between bentazon and the grass herbicides. The grass herbicide treatments provided significantly better visual control than either the bentazon alone or the untreated check. The exceptions were diclofop-methyl at the 0.56 kg/ha rate, and difenopenten at the 0.43 kg/ha rate, both with bentazon at 1.12 kg/ha. As indicated by the dry weights, all treatments with the grass herbicides had significantly lower plant dry weight than when the bentazon was used alone. Only sethoxydim at the 0.56 kg/ha rate, both with and without bentazon, caused significantly lower dry weights than those of the untreated check. The treatments which included bentazon tended to allow more dry weight than similar treatments without bentazon. Highest dry weights occurred with the bentazon alone.

Table 7. Green foxtail visual control (%) and plant dry weights (g) collected September 30, 1981 at Beresford, South Dakota.

Treatment		Green Foxtail	
Herbicide	Rate	Control[a]	Weights[b]
	(kg ai/ha)	(%)	(g)
Diclofop-methyl	0.56	60 A-D[c]	8.0 AB[c]
Diclofop-methyl + Bentazon	0.56 + 1.12	25 DE	15.9 AB
Diclofop-methyl	1.12	55 A-D	17.8 AB
Diclofop-methyl + Bentazon	1.12 + 1.12	58 A-D	12.5 AB
Diclofop-methyl	2.24	76 A-C	6.1 AB
Diclofop-methyl + Bentazon	2.24 + 1.12	54 A-D	8.8 AB
Difenopenten[d]	0.21	63 A-D	6.8 AB
Difenopenten + Bentazon	0.21 + 1.12	53 B-D	14.8 AB
Difenopenten	0.43	75 A-C	11.0 AB
Difenopenten + Bentazon	0.43 + 1.12	35 C-E	13.7 AB
Difenopenten	0.84	78 AB	5.3 AB
Difenopenten + Bentazon	0.84 + 1.12	60 A-D	6.4 AB
Sethoxydim[e]	0.12	84 AB	6.3 AB
Sethoxydim + Bentazon	0.12 + 1.12	63 A-D	10.4 AB
Sethoxydim	0.28	85 AB	10.6 AB
Sethoxydim + Bentazon	0.28 + 1.12	68 A-C	8.7 AB
Sethoxydim	0.56	96 A	2.1 A
Sethoxydim + Bentazon	0.56 + 1.12	91 AB	2.1 A
Bentazon	1.12	5 E	38.3 C
Untreated Check	0.00	0 E	24.9 BC

[a] 0 to 100% scale, 0% = no control, 100% = total control.

[b] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

[c] Values within a column followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[d] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[e] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

The smooth pigweed visual control evaluations made September 30 (Table 8) indicated trends similar to those seen in the July 22 and August 17 evaluations. When the grass herbicides were used in combination with bentazon, a noticeable increase in control over those treatments without bentazon was observed. Sethoxydim with bentazon tended to provide poorer broadleaf weed control as the sethoxydim rate was increased. Plant dry weights at the September 30 harvest did not show any significant differences between treatments. Many grass herbicide treatments, either alone or in combination with bentazon, tended to allow greater dry weight than did the bentazon alone treatment.

Crop injury results as recorded 5 days after application are presented in Table 9. When the grass herbicides were used in combination with bentazon, the injury was higher than when the grass herbicides were applied alone. Difenopenten with bentazon tended to injure the soybean plants less than did the other grass herbicides with bentazon. Bentazon may be responsible for the increased injury.

Crop height measurements recorded August 17 are presented in Table 10. Soybean height tended to be greater when the grass herbicides were applied alone than when they were applied in combination with bentazon. Height reduction may have been due to crop injury induced by the bentazon.

Soybean yields are also included in Table 10. Reduced yields resulted when bentazon was applied in combination with the

Table 8. Smooth pigweed visual control (%) and plant dry weights (g) collected September 30, 1981 at Beresford, South Dakota.

Treatment		Smooth Pigweed	
Herbicide	Rate	Control[a]	Weights[b]
	(kg ai/ha)	(%)	(g)
Diclofop-methyl	0.56	15 D-E[c]	10.3 A[c]
Diclofop-methyl + Bentazon	0.56 + 1.12	59 A-D	9.4 A
Diclofop-methyl	1.12	30 B-E	8.2 A
Diclofop-methyl + Bentazon	1.12 + 1.12	85 A	1.3 A
Diclofop-methyl	2.24	10 DE	8.0 A
Diclofop-methyl + Bentazon	2.24 + 1.12	71 A-C	2.1 A
Difenopenten	0.21	20 C-E	11.3 A
Difenopenten + Bentazon	0.21 + 1.12	50 A-E	2.9 A
Difenopenten	0.43	48 A-E	12.0 A
Difenopenten + Bentazon	0.43 + 1.12	69 A-C	4.4 A
Difenopenten	0.84	49 A-E	1.4 A
Difenopenten + Bentazon	0.84 + 1.12	71 A-C	1.1 A
Sethoxydim	0.12	39 A-E	7.7 A
Sethoxydim + Bentazon	0.12 + 1.12	70 A-C	1.1 A
Sethoxydim	0.28	0 E	18.7 A
Sethoxydim + Bentazon	0.28 + 1.12	61 A-D	0.2 A
Sethoxydim	0.56	24 B-E	4.9 A
Sethoxydim + Bentazon	0.56 + 1.12	50 A-E	5.2 A
Bentazon	1.12	75 AB	2.3 A
Untreated Check	0.00	0 E	8.6 A

[a] 0 to 100% scale, 0% = no control, 100% = total control.

[b] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

[c] Values within a column followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[d] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[e] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

Table 9. Crop injury (%) as observed 5 days after application at Beresford, South Dakota, 1981.

Treatment: Herbicide	Rate	Soybean Injury[a]
	(kg ai/ha)	(%)
Diclofop-methyl	0.56	0 A[b]
Diclofop-methyl + Bentazon	0.56 + 1.12	16 AB
Diclofop-methyl	1.12	0 A
Diclofop-methyl + Bentazon	1.12 + 1.12	19 B
Diclofop-methyl	2.24	1 AB
Diclofop-methyl + Bentazon	2.24 + 1.21	19 B
Difenopenten[c]	0.21	0 A
Difenopenten + Bentazon	0.21 + 1.12	10 AB
Difenopenten	0.43	0 A
Difenopenten + Bentazon	0.43 + 1.12	10 AB
Difenopenten	0.84	0 A
Difenopenten + Bentazon	0.84 + 1.12	10 AB
Sethoxydim[d]	0.12	0 A
Sethoxydim + Bentazon	0.12 + 1.12	16 AB
Sethoxydim	0.28	0 A
Sethoxydim + Bentazon	0.28 + 1.12	16 AB
Sethoxydim	0.56	0 A
Sethoxydim + Bentazon	0.56 + 1.12	13 AB
Bentazon	1.12	6 AB
Untreated Check	0.00	0 A

a 0 to 100% scale, 0% = no control, 100% = total control.

b Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

c Treatments containing difenopenten included crop oil at 0.5% (v/v).

d Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

Table 10. Crop height (cm) measurements recorded on August 17, 1981 and soybean yields (kg/ha) harvested at Beresford, South Dakota.

Treatment		Soybean	
Herbicide	Rate	Height	Yield
	(kg ai/ha)	(cm)	(kg/ha)
Diclofop-methyl	0.56	91.0 AB[a]	2453 A[a]
Diclofop-methyl + Bentazon	0.56 + 1.12	87.0 AB	2244 A-C
Diclofop-methyl	1.12	89.5 AB	2365 A-C
Diclofop-methyl + Bentazon	1.12 + 1.12	89.0 AB	2063 A-C
Diclofop-methyl	2.24	92.5 A	2372 AB
Diclofop-methyl + Bentazon	2.24 + 1.12	88.0 AB	2029 A-C
Difenopenten[b]	0.21	90.0 AB	2460 A
Difenopenten + Bentazon	0.21 + 1.12	88.0 AB	2110 A-C
Difenopenten	0.43	91.5 AB	2365 AB
Difenopenten + Bentazon	0.43 + 1.12	86.0 AB	2197 A-C
Difenopenten	0.84	89.0 AB	2345 AB
Difenopenten + Bentazon	0.84 + 1.12	86.5 AB	1956 BC
Sethoxydim[c]	0.12	91.0 AB	2392 AB
Sethoxydim + Bentazon	0.12 + 0.12	84.0 AB	2211 A-C
Sethoxydim	0.28	89.5 AB	2345 AB
Sethoxydim + Bentazon	0.28 + 1.12	83.5 AB	1855 C
Sethoxydim	0.56	91.5 AB	2278 A-C
Sethoxydim + Bentazon	0.56 + 1.12	82.0 B	1956 BC
Bentazon	1.12	89.0 AB	2177 A-C
Untreated Check	0.00	88.5 AB	2191 A-C

[a] Values within a column followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[b] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[c] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

grass herbicides. This trend was consistent at every herbicide rate. There was a significant correlation of yield with crop height ($R^2 = 0.75$); shorter plants yield less than taller plants. This correlation coincides with the findings of Staniforth and Weber (29).

Effect of time of herbicide application on performance

In the 1980 study, a heavy presure of green foxtail was present. The preplant incorporated application of metribuzin prevented emergence of broadleaf weeds.

Visual evaluations of weed control data in the 1980 experiment are presented in Table 11. A hail storm terminated this study in early August, prior to its planned completion. The evaluation, made August 5 just prior to the hail storm, indicated that sethoxydim provided significantly better control than either of the other two grass herbicides. Visual evaluations of weed control were also made on September 18, 1980, despite the hail storm. Sethoxydim continued to provide significantly better control than the other grass herbicides. With respect to growth stage at the application time, a clear trend was evident toward reduced control with larger weeds. This observation agrees with Schreiber et al. (26) and Harvey et al. (13).

The visual evaluations of green foxtail recorded September 17, 1981 are presented in Table 12. The control with diclofop-methyl is significantly less than the control with the other grass herbicides applied at the one- to three-leaf growth stage. Sethoxydim is significantly more effective than either diclofop-methyl or

Table 11. Green foxtail visual control (%) as observed on August 5 and Septmeber 18, 1980 at Beresford, South Dakota.

Application Date	Application Weed Stage	Check	Diclofop-methyl	Difeno-penten[a]	Sethoxy-dim[b]
		Control[c] (%)			
		August 5, 1980			
7/9/80	2- to 3-Leaf	0 D[d]	18 CD	49 B	91 A
7/17/80	15 to 31 cm	0 D	30 BC	35 BC	86 A
		September 18, 1980			
6/23/81	2- to 3-leaf	0 E[d]	28 D	58 B	94 A
7/1/81	15 to 31 cm	0 E	30 CD	43 C	86 A
7/21/81	41 to 51 cm	0 E	10 E	25 D	71 B

[a] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[b] Treatments containing sthoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] 0 to 100% scale, 0% = no control, 100% = total control.

[d] Values followed by the same letters within the same parameter are not significantly different using Bayes LSD (K ratio = 100).

Table 12. Green foxtail visual control (%) as observed on September 17, 1981 at Beresford, South Dakota.

Application		Treatment		
Date	Weed Stage	Diclofop-methyl	Difenopenten[a]	Sethoxydim[b]
		—— Green Foxtail (%) control[c] ——		
6/23/81	1- to 3-Leaf	49 DE[d]	81 A-C	97 A
7/1/81	3- to 4- Leaf	64 CD	48 DE	99 A
7/16/81	8-Lf to Heading	61 CD	74 A-D	68 B-D
7/21/81	31 to 61 cm	30 EF	44 DE	44 DE
Untreated Check		0 F		

[a] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[b] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] 0 to 100% scale, 0% = no control, 100% = total control.

[d] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

difenopenten when applied at the three- to four-leaf growth stage. When difenopenten was applied at the three- to four-leaf growth stage its effectiveness did not differ significantly from that of the untreated check. All herbicide treatments were superior to the untreated check when applied at the eight-leaf to heading stage of growth, but not significantly different from each other. No herbicide when applied at the 30 to 61-cm growth stage was significantly more effective than the untreated check. Results of the evaluations made July 30 and August 17 were similar to the results above.

The green foxtail dry weights are presented in figures 1, 2, and 3. Each figure presents the data from the untreated check and the three herbicides that were applied on a specific date. This manner of presentation allows for direct comparison of the effects of the individual herbicides when applied at the same time. Thus, the influence of biomass reduction and regrowth can be more easily understood.

The weed dry weight results form the treatments applied June 23, 1981 are presented in Figure 1. The reduction in weed weights throughout the season with sethoxydim tended to be superior to the reduction of the other herbicide treatments. Sethoxydim significnatly reduced the biomass more than did difenopenten at the last harvest date. The sethoxydim significantly reduced the biomass as compared to the untreated check at the second and third collection dates. The season long, biomass reduction suggests that sethoxydim

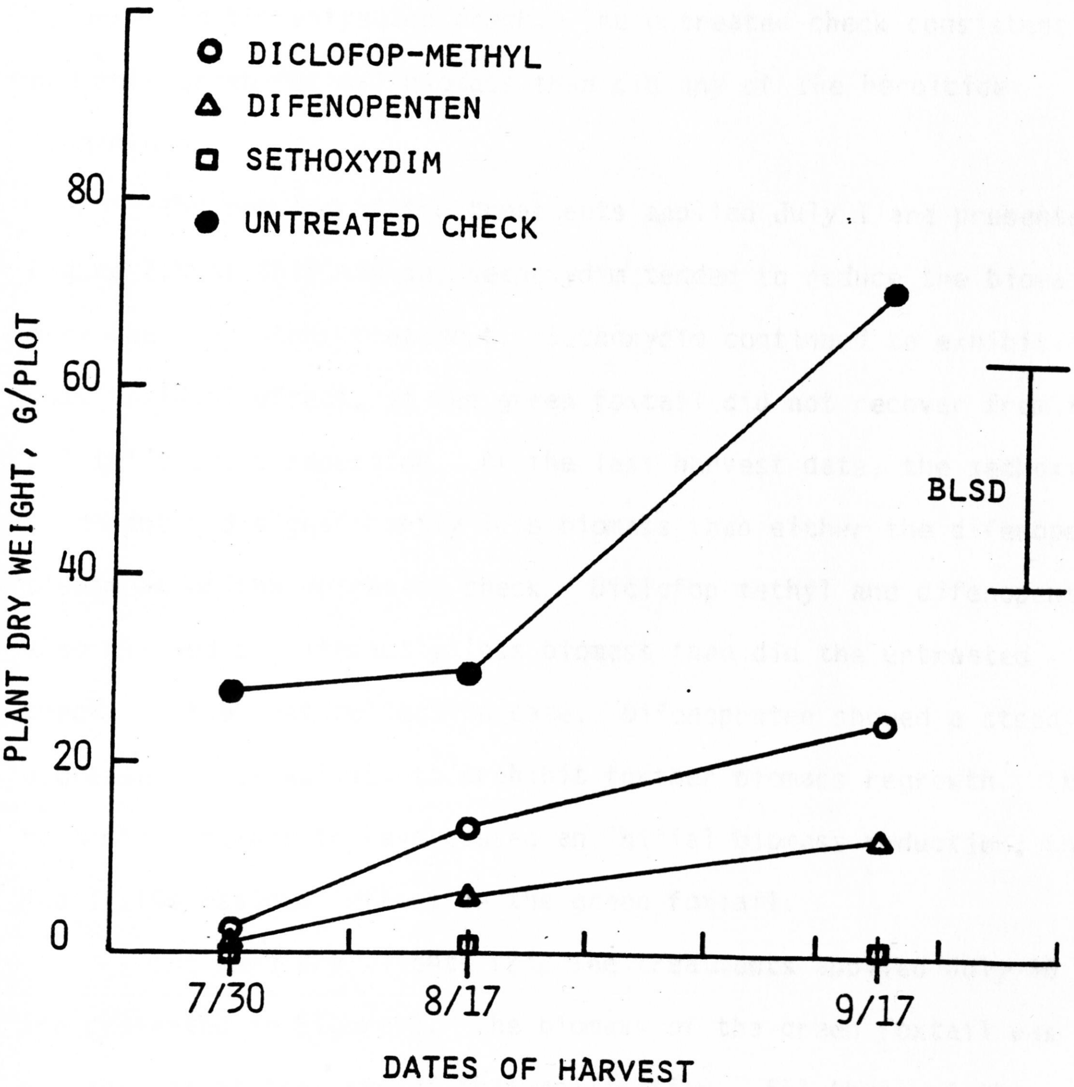

Figure 1. The dry weights of green foxtail as affected by various herbicides applies June 23, 1981 at Beresford, South Dakota.

may have residual activity. Diclofop-methyl and difenopenten significantly reduced the biomass at the last collection date when compared to the untreated check. The untreated check consistently had more green foxtail biomass than did any of the herbicide treatments.

The results of the treatments applied July 1 are presented in Figure 2. At this timing, sethoxydim tended to reduce the biomass more than any other treatment. Sethoxydim continued to exhibit a soil residual effect, as the green foxtail did not recover from the initial biomass reduction. At the last harvest date, the sethoxydim treatment had significantly less biomass than either the difenopenten treatment or the untreated check. Diclofop-methyl and difenopenten also allowed significantly less biomass than did the untreated check, at the last collection date. Difenopenten showed a steady decrease in its ability to prohibit further biomass regrowth. This herbicide appears to have caused an initial biomass reduction, then had little residual effect on the green foxtail.

The weed dry weights from the treatments applied July 16 are presented in Figure 3. The biomass of the green foxtail was substantial at the time of this application. All three of the herbicides appear to have suppressed the regrowth relatively well, but were not able to reduce the existing biomass. No herbicide was significantly different from any other treatment when applied at this application time. At the last harvest date, only diclofop-methyl

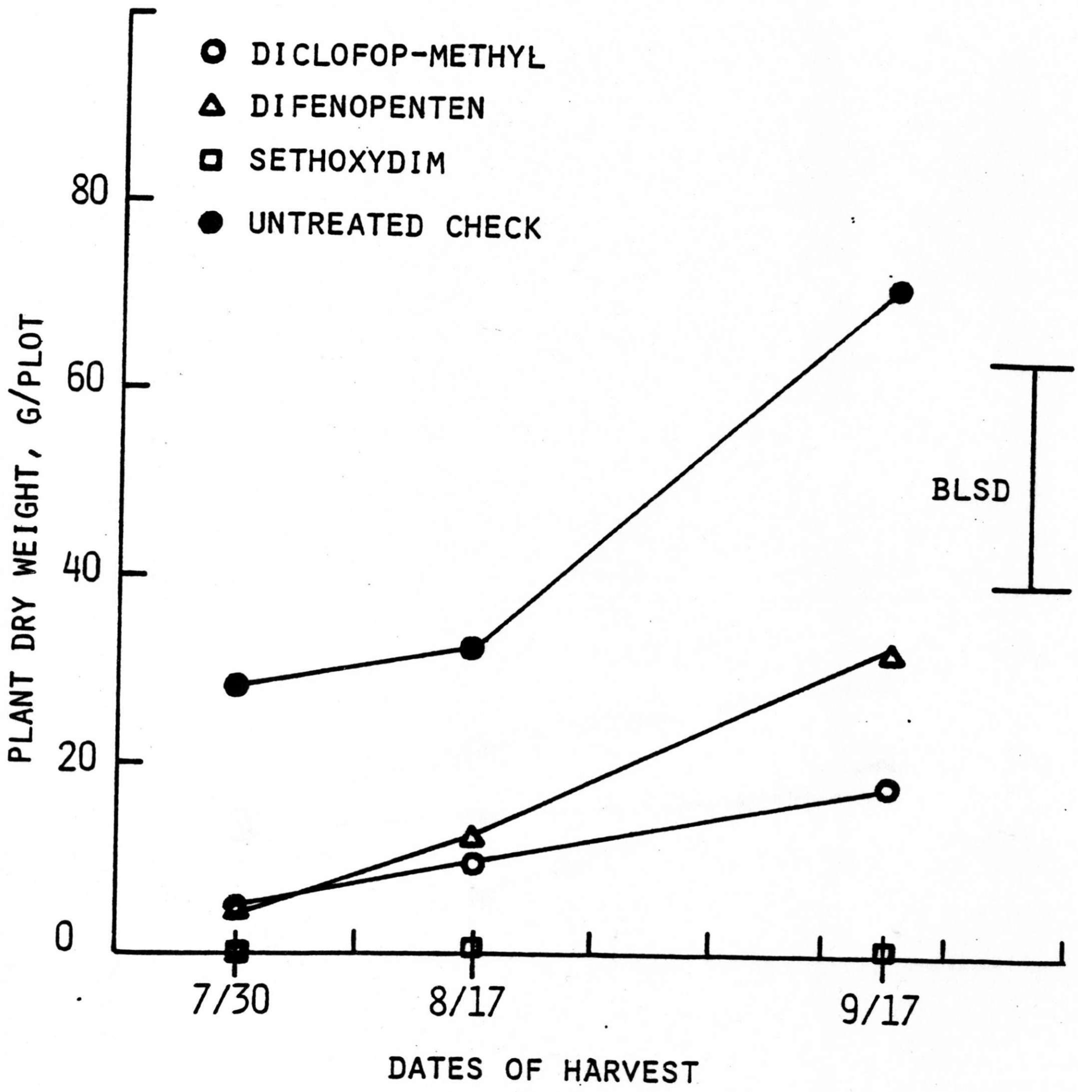

Figure 2. The dry weights of green foxtail as affected by various herbicides applied August 1, 1981 at Beresford, South Dakota.

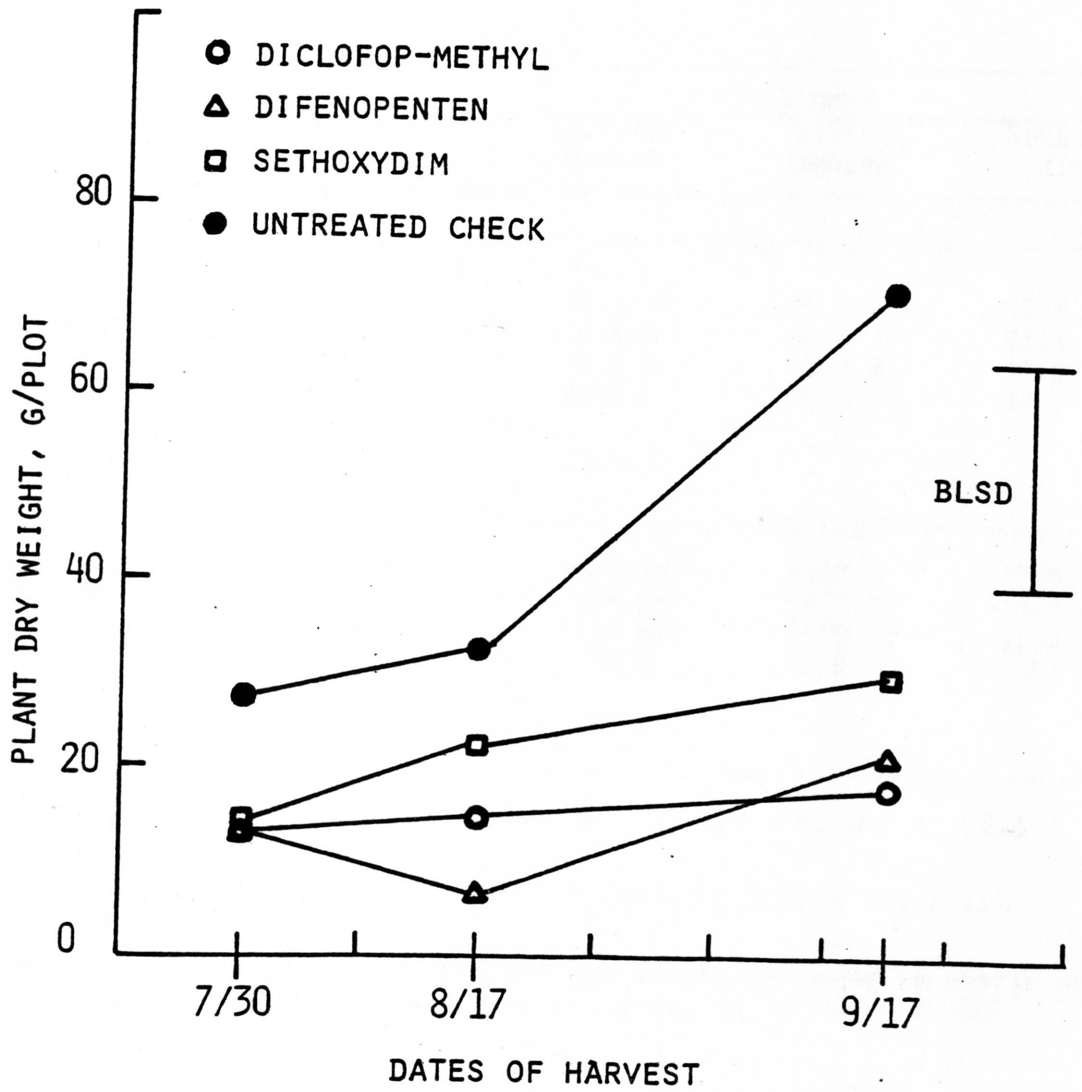

Figure 3. The dry weights of green foxtail as affected by various herbicides applied August 16, 1981 at Beresford, South Dakota.

Table 13. Soybean height (cm) measurements recorded August 17, 1981 and crop yields (kg/ha) harvested at Beresford, South Dakota.

Application Date	Application Weed Stage	Treatment Diclofop-methyl	Treatment Difenopenten[a]	Treatment Sethoxydim[b]
		Crop Height (cm)		
6/23/81	1- to 3-Leaf	82.5 A[c]	85.0 A	82.5 A
7/1/81	3- to 4-Leaf	85.5 A	83.3 A	82.0 A
7/16/81	8-Lf to Heading	84.0 A	83.5 A	85.5 A
7/21/81	31 to 61 cm	80.5 A	80.5 A	83.5 A
	Untreated Check	86.5 A		
		Yield (kg/ha)		
6/23/81	1- to 3-Leaf	1476 AB[c]	1557 A	1528 AB
7/1/81	3- to 4-Leaf	1504 AB	1477 AB	1408 AB
7/16/81	8-Lf to Heading	1514 AB	1479 AB	1563 A
7/21/81	31 to 61 cm	1354 B	1370 AB	1381 AB
	Untreated Check	1085 C		

[a] Treatments containing difenopenten included crop oil at 0.5% (v/v).

[b] Treatements containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] Values followed by the same letters within the same parameter are not significantly different using Bayes LSD (K ratio = 100).

Table 14. Yellow foxtail visual control (%) and plant dry weights (g) collected July 30, 1980 at Brookings, South Dakota.

Appln. Volume	Treatment			
	Control	Diclofop-methyl	Difenopenten[a]	Sethoxydim[b]
(L/ha)	Yellow Foxtail (%) Control[c]			
66	0 C[d]	50 B	60 B	96 A
140	0 C	60 B	63 B	95 A
299	0 C	65 B	68 B	97 A
	Yellow Foxtail Dry Weights[e]			
66	23.7 D-F[d]	19.5 C-E	13.2 B-D	0.0 A
140	32.8 F	9.5 A-C	6.9 AB	3.6 AB
299	31.2 EF	11.6 A-D	14.9 B-D	3.8 AB

[a] Treatments containing difenopenten included the manufacturer's suggested crop oil at 0.5% (v/v).

[b] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] 0 to 100% scale, 0% = no control, 100% = total control.

[d] Values followed by the same letters within the same parameter are not significantly different using Bayes LSD (K ratio = 100).

[e] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

caused significantly lower green foxtail biomass then did the untreated check. The results of the July 21 applications were similar to the July 16 applications.

Soybean plant heights and crop yields are presented in Table 13. The soybean plants in the untreated check tended to be taller than plants in the chemically treated plots. Soybean yields were significantly higher in the treated plots than in the untreated check. Lower soybean yields results when herbicide applications were delayed until after the soybeans flowered. Yield reductions did not occur when weeds were controlled before soybean flowering. This observation is in general agreement with the findings of Knake and Slife (20), who reported that yields are not decreased until giant foxtail is allowed to remain in the crop after the flowering stage of the soybeans. They concluded that postemergence treatments may be effective if preemergence control is not achieved. Dawson (6) suggested a reduction in the amount of light that field beans receive is responsible for the reduced bean yield that results when annual grasses overtop the field beans.

Effect of spray volume on herbicide performance

The visual weed control evaluations and plant dry weights for the trial at Brookings taken on July 30, 1980 are presented (Table 14). The weed control evaluation and plant dry weights taken August 26 were similar. There was no significant response with any of the herbicides to the spray volumes. Sethoxydim at all spray volumes provided significnatly better weed control than any of the other treatments. Only sethoxydim provided greater than 90% control of the yellow foxtail. Yet, both the diclofop-methyl and the difenopenten did control the yellow foxtail significantly better than the control. The plant dry weight results were somewhat different. At the 66 L/ha spray volume, only the sethoxydim provided significnatly lower plant dry weights than any of the other treatments. At the 140 and 299 L/ha volumes, all herbicides were significantly superior to the control, but not significantly different from each other. No significance between treatments was found in the soybean yields (data not shown).

At the Beresford trial, the weed control evaluations indicated that all herbicides provided significnatly superior green foxtail control than the control (Table 15). The herbicides were not significnatly different from each other at the spray volumes of 66 and 299 L/ha. Sethoxydim at the spray volume of 140 L/ha provided significantly superior control than did difenopenten at the same volume. All herbicides, except difenopenten at 66 L/ha, provided greater than 80% control of green foxtail. Only difenopenten appeared to provide significantly superior weed control when spray volume was increased. The plant dry weights indicated that only the sethoxydim at the 66 L/ha spray volume significantly reduced the dry weight more than the control. At the 140 L/ha volume, there was no significant difference between any of the treatments. When compared to the

Talbe 15. Green foxtail visual control (5) and plant dry weights (g) collected September 17, 1981 at Beresford, South Dakota.

Appln. Volume	Treatment			
	Control	Diclofop-methyl	Difenopenten[a]	Sethoxydim[b]
(L/ha)	Green Foxtail (%) Control[c]			
66	0 D[d]	80 BC	79 C	89 A-C
140	0 D	86 A-C	81 BC	94 A
299	0 D	80 BC	91 AB	83 A-C
	Green Foxtail Dry Weights[e]			
66	26.4 BC[d]	9.8 AB	17.5 AB	5.9 A
140	18.8 AB	7.5 A	8.2 A	5.0 A
299	35.2 C	14.6 AB	14.3 AB	15.7 AB

[a] Treatments containing difenopenten included the manufacturer's suggested crop oil at 0.5% (v/v).

[b] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] 0 to 100% scale, 0% = no control, 100% = total control.

[d] Values followed by the same letters within the same parameter are not significantly different using Bayes LSD (K ratio = 100).

[e] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

control, all herbicide treatments at 299 L/ha spray volume significantly reduced the plant dry weights.

Effect simulated rainfall on herbicide performance

A rainfall simulator can be used to determine the rainfast characteristics of postemergence herbicides. The influence on weed control of rainfall following herbicide application can be evaluated by planning the time between application and rainfall. No significant reduction in yellow foxtail control was experienced with diclofop-methyl and difenopenten when rainfall occurred at any interval, from immediate to 8 hours after application (Table 16). Sethoxydim did have a significant reduction in control when the rainfall was immediate when compared to the 2, 4 and 8 hour rainfall intervals. All herbicide treatments provided significantly better weed control than the untreated checks. The yellow foxtail dry weights indicated much the same results. Sethoxydim significantly reduced the weights of yellow foxtail plant dry matter, at the 2, 4 and 8 hour time to rainfall intervals, more than did any of the difenopenten treatments, or diclofop-methyl at the 0.5, 2, 4 and 8 hour intervals, or the controls. All treatments, except the sethoxydim at 0.5, 1, 2, 4 and 8 hour interval and diclofop-methyl at the 1 hour interval, did not significantly reduce the weights more than did the untreated check with rainfall.

Differences in soybean yields were not significant (Table 17), which may be largely due to natural rainfall in the area being

Table 16. Yellow foxtail control (%) and plant dry weights (g) collected August 15, 1981 at Redfield, South Dakota.

Time to Rainfall	Treatment		
	Diclofop-methyl	Difenopenten[a]	Sethoxydim[b]
	Yellow Foxtail (%) Control		
Immediate	68 A-D[d]	45 D	55 CD
0.5 Hour	75 A-C	58 CD	84 A-C
1.0 Hour	66 B-D	65 B-D	80 A-C
2.0 Hours	65 B-D	55 CD	94 AB
4.0 Hours	60 CD	59 CD	97 A
8.0 Hours	68 A-D	69 A-D	97 A
Untreated Check without rainfall			0 E
Untreated Check with rainfall			0 E
	Yellow Foxtail Dry Weights[e]		
Immediate	8.6 A-E[d]	17.0 D-F	12.0 B-E
0.5 Hour	12.1 B-E	12.1 B-E	5.2 A-C
1.0 Hour	8.2 A-D	12.2 B-E	4.3 AB
2.0 Hours	15.8 D-F	16.5 D-F	1.8 A
4.0 Hours	15.0 C-F	11.7 B-E	0.3 A
8.0 Hours	13.8 B-E	11.6 B-E	0.4 A
Untreated Check without rainfall			24.6 F
Untreated Check with rainfall			18.4 EF

[a] Treatments containing difenopenten included the manufacturer's suggested crop oil at 0.5% (v/v).

[b] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] 0 to 100% scale, 0% = no control, 100% = total control.

[d] Values followed by the same letters within the same parameter are not significantly different using Bayes LSD (K ratio = 100).

[e] Weights (g) from two subsamples from a 0.25 m² area were taken from each plot.

Table 17. Soybean yields (kg/ha) harvested at Redfield, South Dakota, 1981.

Time to Rainfall	Treatment: Diclofop-methyl	Treatment: Difenopenten[a]	Treatment: Sethoxydim[b]
	Soybean Yield (kg/ha)		
Immediate	717 A[c]	677 A	597 A
0.5 Hour	583 A	543 A	550 A
1.0 Hour	550 A	617 A	724 A
2.0 Hours	543 A	610 A	791 A
4.0 Hours	550 A	630 A	684 A
8.0 Hours	516 A	583 A	677 A
Untreated Check without rainfall			550 A
Untreated Check with rainfall			557 A

[a] Treatments containing difenopenten included the manufacturer's suggested crop oil at 0.5% (v/v).

[b] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

[c] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

quite low for the season. While not significant, the sethoxydim treatments at the 1, 2, 4, and 8 hours to rainfall intervals were among the highest yielding treatments.

Effect of graminicides for quackgrass control

Quackgrass was the principal weed at the initiation of the trial at Colton. A large population of common sunflower (Helianthus annuus L. # HELAN) and common lambsquarters later developed. In Table 18 the quackgrass control evaluation observed on August 4 is presented. As was found in the evaluation of July 2 (data not shown), difenopenten and sethoxydim increased control with increasing rates. Diclofop-methyl did not significantly control the quackgrass at any rate compared to the untreated check. While the higher rates of both difenopenten and sethoxydim at the two highest rates did provide statistically significant control, it should be pointed out that neither treatment provided greater than 80% control.

Soybean yields were not harvested because of the broadleaf weed pressure. No crop phytotoxicity was observed with any treatment, including the highest rates of all herbicides.

At the Brookings location, the site was maintained broadleaf free. The evaluation and plant dry weights observed on August 19 (Table 19) were very similar to the August 4 evaluations. The visual observations showed that all rates of sethoxydim and difenopenten at 1.28 and 2.55 kg/ha rates provided significantly better control than the untreated check. Diclofop-methyl did not effecitvely control the

Table 18. Quackgrass control (%) as observed on August 4, 1981 at Colton, South Dakota.

Treatment		
Herbicide	Rate	Quackgrass Control[a]
	kg ai/ha	—— (%) ——
Diclofop-methyl	1.68	5 DE[b]
Diclofop-methyl	3.36	0 E
Diclofop-methyl	6.72	3 E
Difenopenten[c]	0.64	5 DE
Difenopenten	1.28	28 C
Difenopenten	2.55	53 A
Sethoxydim[d]	0.43	15 D
Sethoxydim	0.84	35 BC
Sethoxydim	1.68	45 AB
Untreated Check	0.00	0 E

[a] 0 to 100% scale, 0 = No control, 100 = Complete control.

[b] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[c] Difenopenten treatments were in combination with manufacturer's suggested crop oil at 0.5% (v/v).

[d] Sethoxydim treatments were in combination with AtPlus 411-F oil at 1.0% (v/v).

Table 19. Quackgrass visual control (%) and dry weights (g) collected August 19, 1981 at Brookings, South Dakota.

Treatment		Quackgrass	
Herbicide	Rate	Control[a]	Dry Weights[b]
	kg ai/ha	(%)	(g)
Diclofop-methyl	1.68	5 E[c]	15.1 D[c]
Diclofop-methyl	3.36	13 C-E	14.7 D
Diclofop-methyl	6.72	8 D-E	14.1 CD
Difenopenten[d]	0.64	15 C-E	10.8 B-D
Difenopenten	1.28	23 B-E	6.6 A-C
Difenopenten	2.55	25 B-D	7.9 A-D
Sethoxydim[e]	0.43	28 BC	6.3 AB
Sethoxydim	0.84	40 B	5.8 AB
Sethoxydim	1.68	70 A	2.9 A
Untreated Check	0.00	0 E	12.0 B-D

[a] 0 to 100% scale, 0 = No Control, 100 = Complete Control.

[b] Weights (g) from two subsamples from a 0.25 m² area were taken form each plot.

[c] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[d] Difenopenten treatments were in combination with manufacturer's suggested crop oil at 0.5% (v/v).

[e] Sethoxydim treatments were in combination with AtPlus 411-F oil at 1.0% (v/v).

quackgrass. None of the herbicide treatments provided greater than 80% control. The trend was similar with the plant dry weights; however, the significance was not as pronounced. Only the 1.68 kg/ha rate of sethoxydim provided significantly lower quackgrass plant dry weights than did the untreated check. There was a highly significant correlation between the visual evaluation and plant dry weights ($R^2 = 0.86$). This correlation confirms that higher rates of difenopenten and sethoxydim are potentially effective for the control of quackgrass.

Soybean yields reflected the visual observations and plant dry weights. Table 20 summarizes the results of the soybean harvest. Sethoxydim at all rates and difenopenten at the 2.55 kg/ha rate provided significantly higher yields than did the untreated check. There was a highly significant ($R^2 = 0.84$) correlation between the visual quackgrass control evaluations and the soybean yields, which indicates that visually observed weed control can be reflected in the soybean yield outcome. The exceptionally low soybean yields of 134 to 312 kg/ha can possibly be attributed to quackgrass allopathic effects.

Table 20. Soybean yields (kg/ha) harvested at Brookings, South Dakota, 1981.

Treatment Herbicide	Rate	Soybean Yield
	kg ai/ha	- (kg/ha) -
Diclofop-methyl	1.68	208 A-C[a]
Diclofop-methyl	3.36	216 A-C
Diclofop-methyl	6.72	160 BC
Difenopenten[b]	0.64	176 BC
Difenopenten	1.28	239 A-C
Difenopenten	2.55	252 AB
Sethoxydim[c]	0.43	303 A
Sethoxydim	0.84	304 A
Sethoxydim	1.68	312 A
Untreated Check	0.00	134 C

[a] Values followed by the same letters are not significantly different using Bayes LSD (K ratio = 100).

[b] Treatments containing difenopenten included the manufacturer's suggested crop oil at 0.5% (v/v).

[c] Treatments containing sethoxydim included AtPlus 411-F oil at 1.0% (v/v).

SUMMARY AND CONCLUSIONS

Effect of bentazon tank-mixes on herbicide performance

An increase in rates of all grass herbicides will increase the degree of grass control. However, herbicides with bentazon provided less control than the equivalent rate of the same grass herbicide without bentazon. This ineffectiveness could be the result of antagonism between the bentazon and the grass herbicides. Sethoxydim provided the best overall control of green foxtail, as evidenced by both visual weed control evaluations and plant dry weights. Difenopenten was the next best herbicide for green foxtail control, followed by diclofop-methyl. For volunteer corn control, difenopenten appeared to have the greatest herbicidal activity, followed by sethoxydim, then diclofop-methyl.

Bentazon alone provided adequate control of both common lambsquarters and smooth pigweed. However, when bentazon was combined with the grass herbicides, its herbicidal activity was significantly reduced. While the combinations with bentazon were significantly superior to the grass herbicides alone for smooth pigweed control, the tank-mix combinations were consistently inferior to bentazon alone for broadleaf control. This differing effectiveness may have been the result of antagonism between the bentazon and the grass herbicides. It may also have been a partial function of interspecific weed competition, i.e., when the grasses were effectively controlled, the broadleaf weeds were permitted to become established at higher population levels. Sethoxydim was the most effective of the grass herbicides.

Crop height decreased as the rate of the grass herbicides increased. This tendency can be attributed largely to the reduction of the grass competition, which was noted in both years of the study. Crop injury was observed when bentazon was used. This injury took the form of leaf burn and early season stunting, which the soybeans appeared to overcome. Yet, this injury may have been reflected in crop height and yields.

On the basis of the study done in 1981, the observation was made that the bentazon treatments caused a lower yield than the grass herbicides did when applied alone. This result could be due to the early season crop injury that was observed. Grass control had the greatest impact on yields, as evidenced by the high correlation between green foxtail control and yields.

Effect of time of herbicide application on performance

Greater than 80% weed control can be achieved if herbicide applications are made prior to the heading stage of the green foxtail. As indicated by visual evaluations, herbicides applied early consistently evoked higher weed control ratings than applications delayed until the heading stage of the green foxtail. Early applications of sethoxydim most effectively controlled the green foxtail.

The results of the green foxtail biomass weights clearly demonstrate the need for early season control. Less biomass regrowth was recorded when the herbicides were applied to small green foxtail early in the season. The sethoxydim was able to effectively reduce the existing biomass and prevent regrowth when applied at the two early application timings. Sethoxydim appeared to have a soil residual effect on the green foxtail. This substantial reduction was not observed when sethoxydim was applied to green foxtail that was in the heading stage of growth. The other herbicides performed much the same way, but none was as effective as sethoxydim in reducing existing biomass and preventing regrowth.

The time of herbicide application did not significantly influence crop height. However, lower yields resulted when herbicides were applied after the flowering stage of the soybeans. This yield reduction affirms the need for early season grass control.

In both years, the early application of the herbicides resulted in better visual control ratings, lower weed biomass and higher yields. Overall, sethoxydim provided the most effective weed control; difenopenten was second in effectiveness and diclofop-methyl third.

Effect of spray volume on herbicide performance

Weed control with the three herbicides, diclofop-methyl, difenopenten and sethoxydim, was not enhanced at any particular spray volume. Only with difenopenten, at Beresford, was there an increase in visual weed control with increasing water volume.

These visual evaluations were confirmed by the plant dry weights. Weed control with each of the herbicides was unaffected by the water volume difference of from 66 to 299 L/ha. Regardless of the spray volume, sethoxydim was generally the most effective herbicide, providing economic control of both green and yellow foxtail. This fact tended to be supported by both the visual weed control evaluations and the plant dry weights.

Effect of simulated rainfall on herbicide performance

Sethoxydim was the best herbicide for yellow foxtail control. The control of yellow foxtail was reduced when rainfall occurred immediately after application of sethoxydim. A time interval of 0.5 to 1 hour between application of sethoxydim and rainfall was necessary to prevent loss of weed control. Rainfall occurring at any interval after application did not reduce the efficacy of the diclofop-methyl or difenopenten; however, these herbicides were not as effective for the control of yellow foxtail as the sethoxydim.

Effect of graminicides for quackgrass control

Control of a rhizomatous perennial grass such as quackgrass is difficult in soybeans. Control possibilities have been limited because of the ability of quackgrass to break bud dormancy throughout the growing season. Of the three grass herbicides tested, two show promise for possible quackgrass control. Sethoxydim provided some quackgrass suppression at all rates, from 0.43 to 1.68 kg/ha.

Sethoxydim does provide the best quackgrass suppression; however, economic control is likely to be economically unfeasible because of the cost of the herbicide at these rates. A grower should be prepared for 50 to 75% control of quackgrass only. Difenopenten at 2.55 kg/ha did provide limited control. Diclofop-methyl should not be considered for quackgrass control at rates up to 6.72 kg/ha.

The soybeans appear to be tolerant to the compounds at the rates tested. No crop injury was noted throughout the tests. Crop yields appear to be influenced by the quackgrass control.

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